PERFORMANCE CHARACTERISTICS OF THE INLET SECTION OF A SCREW CONVEYOR

C. S. Chang, J. L. Steele

ABSTRACT. *An inlet section of a screw conveyor with a hopper was constructed for experiments. The incline angle, hopper length, and rotation speed of the conveyor were adjustable and different types of screw flights could be installed to evaluate the effects of flight type, incline angle, intake length, and rotation speed on grain damage, power requirement, conveying capacity, and conveying energy efficiency. Two corn lots were used for the experiments. Lot A was natural air dried with a moisture content of 12% (w.b.) and a Stein breakage susceptibility of 1.3%. Lot B was high temperature air dried with a moisture content of 12% and a Stein breakage susceptibility of 27.9%. Flight type and rotation speed had significant effect on corn breakage. The grain breakage caused by the conveyor was significantly higher for high temperature dried corn than for natural air dried corn. The conveyor with a double flighting required less power and provided higher conveying capacity and energy efficiency, but caused more damage to the corn compared with other flight types. The conveyor required more power and the conveying capacity and energy efficiency were higher when operated at a 30° incline angle compared to a 40° angle. The conveyor equipped with a long intake hopper increased the capacity slightly but required more power to operate.* ***Keywords.*** *Augers, Conveyors, Corn, Grain damage.*

Screw conveyor are the most common equipment used for moving grain and feed on farms. They possess the advantages of low initial cost, low maintenance, simple construction, and easy mobility. Bloome et al. (1976) indicated that capacity of a screw conveyor is affected by its diameter, intake length, angle of elevation, speed, and moisture content of grain. The length of a screw conveyor will affect power but not capacity. They also indicated that power requirements increase with angle of elevation to 45°, then decrease as the angle goes to 90° and that as angle of elevation increases from 0° to 90°, conveyor capacity decreases. Numerous studies of throughput and power requirements of screw conveyors indicated that conditions existing at the inlet to the conveyor frequently govern performance of the conveyor and that increased length of the exposed screw increased conveyor throughput (Konig and Riemann, 1960; O'Callaghan, 1962; White et al., 1962).

White et al. (1962) indicated that screw conveyor capacity increased with screw speed until some limiting capacity was reached. Lack of increased screw capacity at high speeds probably resulted from increased centrifugal force acting on the grain at the outer edges of the screw. Such action forces grain away from the screw intake and impedes flow into the screw. Also, conveyor capacity is dependent on intake exposure and will increase with exposure length until some maximum capacity is attained. Therefore, maximum capacity can best be obtained with an optimum combination of exposure length and screw speed. They also indicated that modifying the conveyor with an inlet section of double flighting produced an increase in capacity.

O'Callaghan (1962) studied the influence of intake length on power requirements for vertical screw conveyors operating at different speeds. He reported that it is more power efficient to obtain a given discharge at the lowest possible speed by increasing the intake length and that there is an optimum combination of intake length and rotation speed for efficient conveyance.

Konig and Riemann (1960) examined the influence of inlet screw diameter on screw conveyor capacity and found a nearly linear increase in capacity with increased inlet-screw diameter up to a maximum point. After that point, capacity decreased. However, power required continued to increase with inlet-screw diameter after the optimum diameter for capacity was reached.

In studies with a vertical conveyor, O'Callaghan (1962) developed guide vanes to reduce agitation of material at the screw conveyor inlet. Use of guide vanes nearly doubled the capacity of a vertical screw conveyor for speeds from 600 to 1000 rpm. He also observed that approximately 33% of the total power to drive a 3-m long conveyor was used at the inlet. Stevens (1962) tested performance of several auger conveyors. He indicated that less than 50% of the power was used in moving grain along the tube. Some of the extra power required must be consumed at the intake hopper, where considerable circulation of grain was observed.

Grain damage is of major concern to the grower, grain elevator operator, grain processor, and exporter of grain and grain products. In many instances, damaged grain

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The authors are **Cheng S. Chang,** ***ASAE Member Engineer***, Agricultural Engineer, and **James L. Steele,** ***ASAE Member Engineer***, Agricultural Engineer, Grain Marketing and Production Research Center, ARS, USDA, Manhattan, Kans. **Corresponding author:** C. S. Chang, USDA-ARS, Grain Marketing and Production Research Center, 1515 College Ave., Manhattan, KS 66502; tel.: (913) 776-2729; fax: (913) 776-2792.

commands a lower price and causes problems in export markets. Insects contaminate broken kernels more readily than intact kernels. Physically damaged grain is satisfactory for animal feed, but produces inferior food products in many situations. Bouse et al. (1964) analyzed damage to castor beans in screw conveyors. They found that increasing rotational speed caused greater damage, and that clearance between conveyor casing and screw flighting was important in reducing the amount of seed damaged by the screw conveyor. Misra et al. (1991) studied several conveying systems with respect to their effect on soybean seed quality. They found that the steel-flighting conveyor produced 4.3% seed coat damage in two consecutive passes and the rubber-intake conveyor (a two-foot rubber flighting intake section connected to the main steel flighting section) produced 2.8% damage. These results implied that at least 35% of the total seed coat damaged occurred at the inlet for steel-flighting conveyors.

Sands and Hall (1971) studied shelled corn damage during transport in a screw conveyor. They found that the conveyor caused a small amount of damage to dry corn when operated at full capacity, but the level of damage increased greatly when the conveyor was operated at 1/4 capacity. If corn had been dried at a high temperature, the level of damage was higher. As screw speed increased, the level of damage increased. Inclination angle had little effect on the amount of damage to shelled corn in a screw conveyor.

Although capacity and power requirements of screw conveyors have been analyzed, limited work has been done to assess grain damage in screw conveyors. The objectives of this study were to determine effects of flight configuration, incline angle, intake length, and rotation speed of an inlet section of a screw conveyor on grain damage, power requirement, conveying capacity, and conveying energy efficiency.

Materials and Equipment

An inlet section of a 15.2-cm (6-in.) diameter screw conveyor with a hopper (fig. 1) was constructed for experiments. The hopper was 29 cm (11.5 in.) wide at the bottom, 53 cm (21 in.) wide at the top opening, and 41 cm (16 in.) high with inclined side walls (17° from vertical). The screw flight was 13.4 cm (5.3 in.) in diameter. The hopper length, incline angle, and rotation speed of the conveyor were adjustable. The inlet section was designed so that different types of screw flights could be installed for tests. The conveyor was driven by a 746 W (1 hp) motor through a set of pulleys. The desired flight rotation speeds were obtained by selecting different pulley combinations. A torquemeter (model MCRT 24-02T, S. Himmelstein and Co., Hoffman, Ill.) was installed between the drive and flight shafts to monitor rotation speed and torque applied to flight shaft.

Two intake hopper lengths (25 and 41 cm; 10 and 16 in.), two incline angles (30° and 40°), two rotation speeds (413 and 690 rpm ± 2 rpm) and three types of screw flighting (fig. 2) were used in the experiments. Type A flight was a single flight standard pitch screw, type B was a double flight standard pitch screw, and type C was a single flight standard pitch screw with a 0.12 × 1.9-cm (1/8 × 3/4 in.) wide strip welded to the outer edge of the screw.

Two corn lots were used for the experiments. Lot A was natural-air dried with a moisture content of 12% (w.b.), test weight of 780 kg/m^3 (60.5 lb/bu), and a Stein breakage susceptibility of 1.3%. Lot B was high temperature air dried [drier plenum temperature = 145°C (293°F)] with a moisture content of 12%, test weight of 774 kg/m^3 (60 lb/bu), and a Stein breakage susceptibility of 27.9%. Both corn lots were cleaned with an Eureka Continental Cleaner, Model Mark II (S. Howes Co., Inc. Silver Creek, N.Y.) before tests. Two sizes of sieves [15.9 × 12.7 mm (5/8 in. × 1/2 in.) oblong hole and 5.2 mm (13/64 in.) round hole] were used in the cleaner. They were placed in series so that corn passed the oblong-hole sieves first then through the round-hole sieves.

Corn damage tests were initiated by placing each lot of corn 907 kg (2,000 lb) in a hopper bottom bin with an adjustable gate at the bottom. Corn was transferred through the gate, into the conveyor hopper, and fed through the conveyor into another hopper bin. The gate opening was manually adjusted during the test so that corn in the conveyor hopper was maintained at full level up to the top edge of the hopper. Each test lot was repeatedly run through the conveyor 10 times. Then it was fed through a grain cleaner with a 4.8 mm (12/64 in.) round-hole cylindrical sieve (Carter-Day Precision grader, Style ZP4, Carter-Day Co., Minneapolis, Minn.) to determine corn breakage. Weight of materials which passed through the sieve was used to calculate percentage of broken corn and fine materials (BC). Two replicated tests were conducted for each variable (treatment) combination.

69%
lines for position only

Figure 1–Inlet section of experimental conveyor.

50%
lines for position only

Figure 2–Experimental screw flights: A – single flight, standard pitch; B – double flight, standard pitch; C – single flight, standard pitch with a strip welded to the outer edge of the screw.

The same weight of corn from each lot was used to determine the power requirements and conveying energy efficiency. Rotation speed and torque measured by the torquemeter during each test were recorded in a data acquisition system. Conveying time for each test was determined from the torque measurements. Test time started when the measured torque reached halfway between no-load and full-load and ended when the torque reduced to halfway between full-load and no-load. Four replicated tests were conducted for each variable combination. Power required for the conveyor was calculated using equation 1 with measured rotation speeds and torques:

$$P = 2\pi\tau\omega \tag{1}$$

where
P = power (W)
τ = torque (N·m)
ω = rotation speed (r/s)

Conveying energy efficiency, which was defined as the quantity of grain conveyed per unit energy input to the conveyor, was calculated using equation 2:

$$E = Q/(T\ P) \tag{2}$$

where
E = conveying energy efficiency (t/W·h)
Q = grain weight (t)
T = conveying time (h)

Results and Discussion

Table 1 shows the average values of broken corn and fine material (BC), power requirements, conveying capacity, and conveying energy efficiency for both corn lots A and B. Statistical analysis of test data showed significantly higher (3.8 times) grain breakage for high temperature dried corn (Lot B) than for natural-air dried corn (Lot A), and that flight type and rotation speed significantly ($p = 0.01$) affected grain breakage (SAS, 1996). However, the range of incline angle and intake length tested did not significantly affect grain breakage. All four conveyor parameters, rotation speed, flight type, incline angle, and intake length significantly ($p = 0.01$) affected power requirement, conveying capacity, and conveying energy efficiency for both lots.

Average BC was 0.33% for lot A and 1.24% for lot B. BC was higher (12 to 13%) in both corn lots when grain was conveyed at high speed than at low speed. Flight type A (single flight standard pitch) caused the least damage and flight type B (double flight standard pitch) caused the most damage among the three flight types tested at both speeds (tables 2 and 3). Corn damaged by conveying was less for the grain dried with natural air. Sands and Hall (1971) reported that damage to ambient-air dried corn was 1.2% and high-temperature dried corn was 2.5% when grain (13% moisture) was conveyed through a 30-m (100-ft) long, 15-cm (6-in.) diameter screw conveyor operated at 50° incline angle and 550 rpm.

Table 1. Average BC, power requirements, conveying capacity, and conveying energy efficiency of the inlet section of a screw conveyor

Conveyor Parameters		BC (%)		P (W)		Q (t/h)		E (t/W·h)	
		Lot A	Lot B	Lot A	Lot B	Lot A	Lot B	Lot A	Lot B
Rotation speed (rpm)	413	0.31	1.17	189	209	32.1	24.9	0.167	0.117
	690	0.35	1.31	338	350	42.8	34.0	0.123	0.095
Flight type	A	0.30	1.01	261	280	39.6	31.0	0.155	0.114
	B	0.35	1.38	245	263	42.2	33.1	0.175	0.128
	C	0.33	1.33	283	298	30.6	24.1	0.111	0.083
Incline angle (°)	30	0.33	1.22	272	289	39.2	31.0	0.145	0.108
	40	0.32	1.25	255	272	35.7	27.8	0.139	0.102
Intake length (cm)	25.4	0.34	1.20	211	223	36.1	27.5	0.170	0.122
	40.6	0.32	1.28	316	337	38.8	31.3	0.121	0.091

NOTE:
BC = broken corn and fine materials; P = power requirements;Q = conveying capacity; E = conveying energy efficiency; Lot A = corn lot A, natural-air dried; Lot B = corn lot B, high-temperature dried; W = 0.00134 hp; t/h = 39 bu/h; t/W·h = 29104 bu/hp·h; A = single flight; B = double flight; C = single flight with a strip welded to the outer edge of the screw.

Table 2. Average BC, power requirements, conveying capacity, and conveying energy efficiency of the inlet section of a screw conveyor at two speeds for natural air dried corn (Lot A)

Conveyor Parameters		Speed at 413 rpm				Speed at 690 rpm			
		BC (%)	P (W)	Q (t/h)	E (t/W·h)	BC (%)	P (W)	Q (t/h)	E (t/W·h)
Flight type	A	0.28	188	34.6	0.186	0.32	335	44.5	0.133
	B	0.33	183	35.0	0.193	0.37	307	49.3	0.161
	C	0.30	196	26.6	0.135	0.36	371	34.5	0.094
Incline angle (°)	30	0.31	195	33.7	0.172	0.36	348	44.7	0.125
	40	0.31	182	30.5	0.163	0.34	327	40.8	0.121
Intake length (cm)	25.4	0.32	144	31.4	0.213	0.35	277	40.7	0.142
	40.6	0.29	233	32.8	0.137	0.34	398	44.8	0.109

NOTE:
BC = broken corn and fine materials; P = power requirements;
Q = conveying capacity; E = conveying efficiency; W = 0.00134 hp;
t/h = 39 bu/h; t/W·h = 29104 bu/hp·h.

Table 3. Average BC, power requirements, conveying capacity, and conveying energy efficiency of the inlet section of a screw conveyor at two speeds for high temperature dried corn (Lot B)

Conveyor Parameters		Speed at 413 rpm				Speed at 690 rpm			
		BC (%)	P (W)	Q (t/h)	E (t/W·h)	BC (%)	P (W)	Q (t/h)	E (t/W·h)
Flight type	A	0.96	204	26.3	0.130	1.06	356	35.6	0.101
	B	1.31	208	27.7	0.134	1.45	317	38.6	0.122
	C	1.24	217	20.6	0.095	1.42	378	27.7	0.074
Incline angle (°)	30	1.16	218	26.3	0.120	1.29	359	35.8	0.098
	40	1.18	201	23.5	0.114	1.32	342	32.1	0.092
Intake length (cm)	25.4	1.09	163	23.8	0.142	1.31	283	31.3	0.107
	40.6	1.25	256	26.0	0.099	1.31	418	36.7	0.085

NOTE:
BC = broken corn and fine materials; P = power requirements;
Q = conveying capacity; E = conveying efficiency; W = 0.00134 hp;
t/h = 39 bu/h; t/W·h = 29104 bu/hp·h.

Average conveying capacities were 37.5 t/h (1473 bu/h) and 29.5 t/h (1159 bu/h) for corn lots A and B, respectively. Conveyor capacity was affected by the characteristics and conditions of the grain conveyed. The conveying capacity was 33 to 37% higher at the high rotation speed compared to the low rotation speed. At the high rotation speed, the conveyor required 67 to 79% more power and reduced the conveying energy efficiency by 19 to 26% compared to the low rotation speed. The average power requirements ranged from 189 to 209 W (0.25 to 0.28 hp) at low speed and from 338 to 350 W (0.45 to 0.47 hp) at high speed. Based on the power requirements for a 3-m (10 ft) long and 15.2-cm (6 in.) diameter screw conveyor reported by White et al. (1962), the power requirements for the inlet section tested were about 28 to 33% of the total power requirements for the 3 m (10 ft) long conveyor. Bloome et al. (1976) reported that the conveying capacities (corn at 14.5% moisture) and power requirements for a 3 m (10 ft) long 15 cm (6 in.) diameter screw conveyor were 21.6 t/h (850 bu/h) and 656 W (0.88 hp), respectively, at a speed of 400 rpm, and 29.5 t/h (1160 bu/h) and 954 W (1.28 hp), respectively, at a speed of 600 rpm when the conveyor was operated at 45° incline angle with an intake hopper length of 30 cm (1 ft).

Flight type B required the least power and had the highest capacity and energy efficiency among the three flight types tested. The conveyor required 6 to 7% more power, the conveying capacity was 10 to 12% higher, and the energy efficiency was 4 to 6% higher when operated at a 30° incline angle compared to a 40° incline angle. Equipping the conveyor with a long intake length (41 cm; 16 in.) slightly increased the capacity (7 to 14%), but required about 50% more power and reduced the conveying energy efficiency by 25 to 29%. The effects of operation parameters (speed, flight type, incline angle, and intake length) on conveyor performance (BC, power requirements, capacity, and energy efficient) were similar for both corn lots.

Conclusions

Corn breakage was significantly affected by the flight type and rotation speed. Damage caused by the conveyor was less for corn dried with low temperature air than for corn dried with high temperature air. Flight type B (double flight standard pitch) required less power and provided higher conveying capacity and energy efficiency, but caused more damage to the corn as compared to the conveyor with other types of flighting. Flight type A (single flight standard pitch) caused the least damage to corn, and performance, in terms of power requirement, capacity, and conveying efficiency, was between the conveyor with flight types B and C. Equipping the conveyor with a long intake hopper slightly increased the capacity, but required significantly more power.

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